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Symptoms at Exhaustion from Uncompensable Exercise-Heat Stress

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Summary

Exhaustion occurs over a broad range of core temperatures during uncompensable exercise-heat stress. This study examined the symptoms at heat exhaustion and whether they differed among individuals terminating exercise at low vs. high core temperatures. Forty-seven healthy, heat-acclimated volunteers exercised to exhaustion during uncompensable heat stress on one or more occasions for a total of 133 trials. Mean core temperature (±sd) at exhaustion was 38.7±0.5°C (range 37.4 to 39.8°C) and was generally consistent within an individual. Volunteers stopped primarily due to ataxia/dizziness (42%), followed by physical exhaustion (25%), headache/nausea (17%), dyspnea (12%) and muscle cramps (4%). Volunteers who terminated at lower core temperatures (≤38.4°C) were limited by physical exhaustion at a rate similar to those stopping at higher (≥39.0°C) core temperatures. However, those who stopped at lower core temperatures had a higher incidence of dyspnea and lower incidence of both ataxia/dizziness and headache/nausea when compared to volunteers terminating exercise at higher core temperatures ($\chi^2 = 10.6$; $P<0.05$). Therefore, heat intolerant persons were more likely to develop respiratory distress while heat tolerant persons were able to continue until cardiovascular and illness symptoms limited further effort. These data suggest that different physiological mechanisms contribute to the inter-subject variability in tolerance to uncompensable exercise-heat stress.

Background

Uncompensable heat stress exists when evaporative capacity of the environment is inadequate to remove the heat being produced. Workers wearing protective clothing such as firefighters, toxicological clean-up workers, soldiers on a chemical-biological battlefield, and others performing strenuous exercise in oppressively hot/humid conditions are exposed to uncompensable heat stress. Under such stress, workers frequently develop symptoms of heat exhaustion and cannot continue to work. Our laboratory (3,4,6,8,9) as well as others (1,5) have reported that soldiers become exhausted over a broad range of core temperatures during uncompensable heat stress. In contrast, authors of studies using trained athletes have reported that all their subjects uniformly became exhausted at relatively high core temperatures (2,7). We hypothesized that the different results between studies might be due to different study populations. To identify if the symptoms at exhaustion differed among individuals terminating exercise at low vs. high core temperatures, we examined the symptoms at exhaustion from several studies our laboratory had conducted over the years (3,4,6,8,9).

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Methods

Subjects. Forty-seven healthy, heat acclimated soldiers (age 23±5 y, body mass 77±11 kg, body surface area 1.94±0.15 m^2, maximal oxygen consumption 54±7 ml $\cdot kg^{-1} \cdot min^{-1}$) participated as study volunteers after signing an approved informed consent document.

Protocol. Volunteers performed treadmill exercise or roadmarching until they could not continue to exercise on one or more occasions. Uncompensable exercise-heat stress was produced by encapsulating the volunteers in chemical protective clothing (38 volunteers) and/or raising the climatic heat stress to levels restricting heat loss (9 volunteers). The protective clothing consisted of trousers, coat, vinyl overboots, butyl rubber gloves, and chemical protective mask (M-17A1) with impermeable hood and Kevlar helmet. The ensemble was worn over T-shirt, shorts, socks and combat boots. Walking speeds were 1.34 to 1.56 m/sec. Rectal and skin temperatures, and heart rate were measured throughout the exercise period. At exhaustion, volunteers self-reported their reason for discontinuing exercise. The reasons for discontinuation were subsequently placed into one of 6 categories: 1) Syncope/ataxia/dizziness, 2) fatigue, 3)Dyspnea, 4) Muscle cramps, 5) headache/nausea.

Data Analysis. Frequency distributions of core temperatures and symptomatology at exhaustion were determined. The data were then subdivided into two groups, those with core temperatures ≤38.4°C or ≥ 39.0°C at exhaustion and chi square analysis was performed to determine if symptoms at exhaustion differed between the two groups. The core temperatures used were picked as they are 0.3°C above and below the mean core temperature at exhaustion, and this difference is the typical between-subjects standard deviation for the core temperature response to exercise. A $p<0.05$ was used to determine statistical significance. Data are presented as mean±sd.

Results

A total of 133 trials ended due to exhaustion from exercise-heat stress that also had available endpoint core temperature and reason for termination. Figure 1 presents the frequency of exhaustion relative to end-point rectal temperature for these trials. Core temperature at exhaustion averaged 38.7±0.5°C with a median temperature of 38.6°C. Exhaustion occurred over a broad range of temperatures (range 37.4°C to 39.8°C).

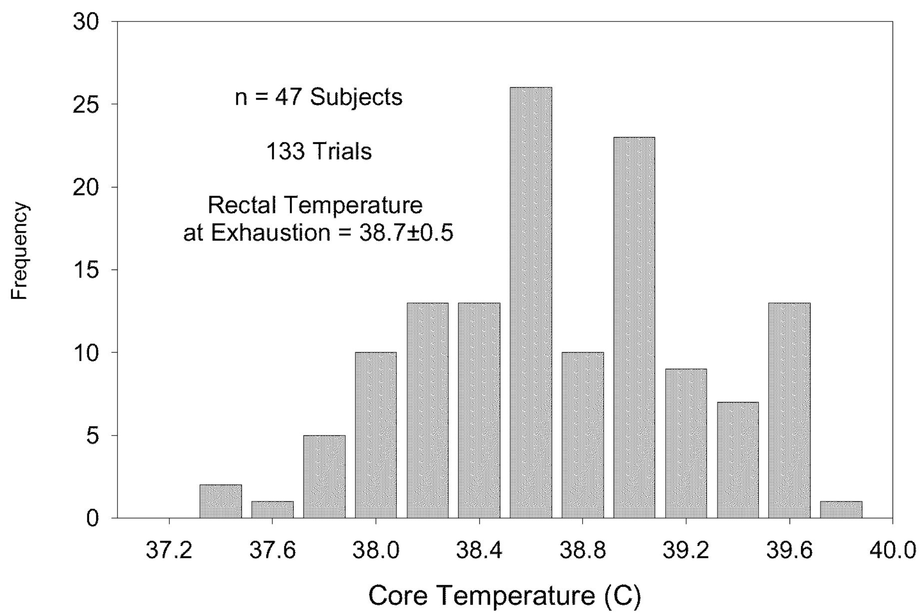

Figure 1. Core temperatures at exhaustion from uncompensable exercise-heat stress.

Figure 2 presents the reason volunteers terminated exercise. Symptoms of syncope/ataxia/dizziness (42% of cases) were the most frequently cited reasons for being unable to continue exercise. Next most frequent were symptoms of fatigue (25%) followed by headache, sickness (17%) , dyspnea (12%) and muscle cramps (4%).

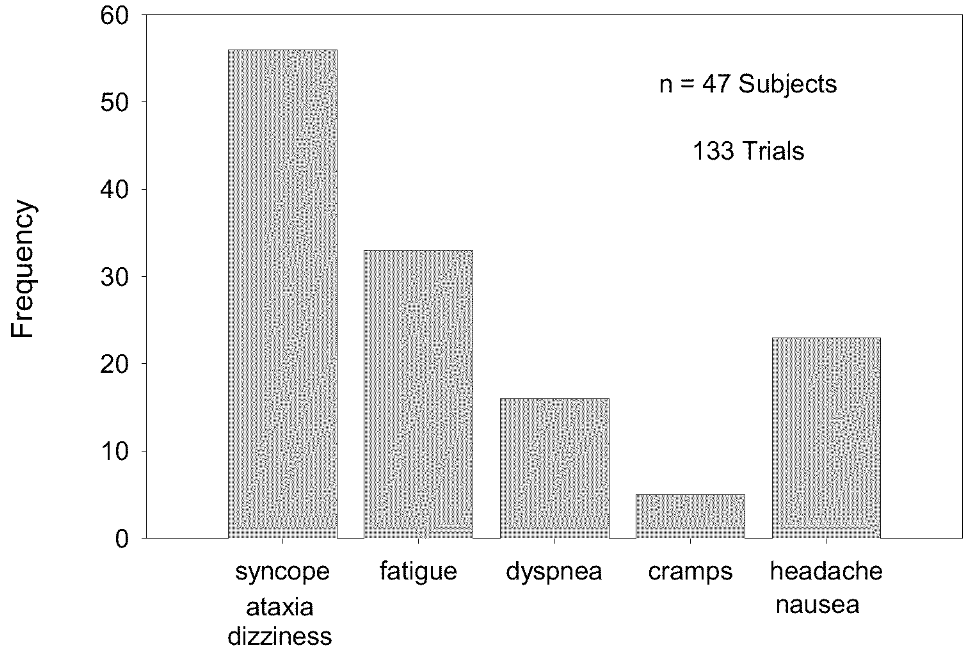

Figure 2. Frequency of symptoms at exhaustion from uncompensable exercise-heat stress.

Separating the cases into two groups based on end-point core temperature revealed a differing set of symptoms between the two groups (Figure 3 and Table 1). Those terminating at core temperatures equal to or below 38.4°C had a higher incidence of dyspnea and lower incidence of syncope/ataxia/dizziness and headache/nausea compared to the group terminating exercise at core temperatures equal to or greater than 39.0°C.

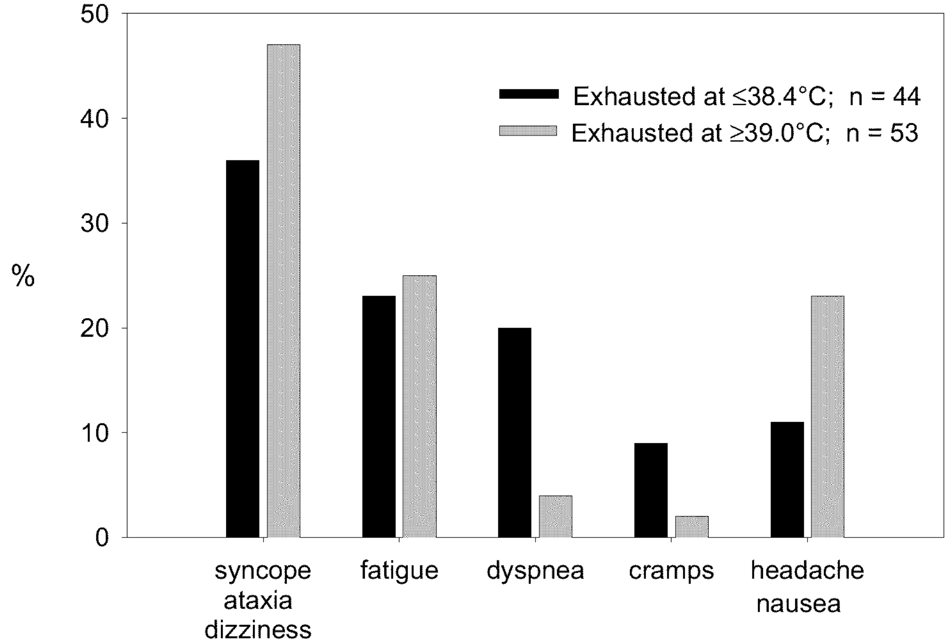

Figure 3. Frequency of symptoms for persons exhausted at low and high core temperatures.

Table 1. Frequency of reason for termination of uncompensable exercise-heat stress for persons with low (≤38.4°C) and high (≤39.0°C) core temperatures at exhaustion.

Temp (°C)	Syncope Ataxia Dizziness	Fatigue	Dyspnea	Cramps	Headache Nausea	Σ
≤38.4°C	16 (36%)	10 (23%)	9 (20%)	4 (9%)	5 (11%)	44
≤39.0°C	25 (47%)	13 (25%)	2 (4%)	1 (2%)	12 (23%)	53
Σ	41 (42%)	23 (24%)	11 (11%)	5 (5%)	17 (18%)	97

Low vs. High Core Temperature at Exhaustion: χ^2 critical= 9.488
χ^2 calculated= 10.62
$p < 0.05$

Discussion

Recent laboratory research has focused on relationships between physiological strain and the incidence rate of exhaustion from heat strain during uncompensable heat stress (1,3-6,8,9). Studies using physically active but not highly endurance trained volunteers have reported that exhaustion occurred over a broad range of core temperatures. In contrast, studies using endurance trained athletes have reported that core temperatures at exhaustion occurred consistently over 39.5°C (2,7). From the latter studies, has come the idea that there is a critical core temperature and when this temperature is reached, symptoms of fatigue prevent further exercise. We hypothesized that the populations participating in the studies may have contributed to the disparate observations regarding core temperatures at exhaustion. To test this hypothesis, we retrospectively culled the individual reasons for stopping exercise from several studies our Institute had

performed over the years in which volunteers were asked to complete an prescribed exercise duration or exercise as long as possible during uncompensable exercise heat stress. It was anticipated that if the hypothesis were true, the reasons for termination would be different for those individuals who terminated exercise at low core temperatures compared to individuals who did not terminate until core temperature was above 39°C.

Our results support our hypothesis, as the symptomatology at termination of exercise differed between individuals forced to terminate at low core temperatures compared to those who terminated with core temperatures in excess of 39°C degrees. Those who terminated at low core temperatures had a disproportionate number of cases of dyspnea (20% vs 4% of trials) and fewer cases of syncope/ataxia/dizziness and headache/nausea (50% vs 70%) compared to the volunteers who fatigued when core temperatures were in excess of 39°C. Thus, these data suggest that two separate populations of volunteers participated in the studies. Those stopping at low core temperatures stopped more frequently for symptoms related to respiratory distress and muscle cramps, whereas those stopping at higher core temperatures either had limited symptoms of respiratory distress and muscle cramps or were able to tolerate them until the point of cardiovascular instability (syncope/ataxia/dizziness) or heat illness (syncope/ataxia/dizziness and headache/nausea) were attained.

While it is possible that the experimental conditions did impose an added respiratory load and this contributed to the cases of dyspnea, efforts were made to minimize the detrimental effects of wearing protective clothing on the volunteers' motivation to work. All volunteers were required to have prior experience wearing the protective ensemble before being allowed to participate in the studies and in many cases volunteers participated in an acclimation protocol in which they wore the mask for progressively longer periods of time before performing exhaustive exercise. Additionally, in 79 of 124 trials in which protective clothing was worn, the air filter canisters and voice emitter box were removed to minimize respiratory work during exercise. Despite these precautionary steps, dyspnea was the reason cited in 9 of 44 trials (20%) that terminated at core temperatures ≤38.4°C. Trials where the air canister and voice emitter were worn accounted for 3 of 9 cases. No cases of dyspnea occurred when the chemical protective mask was not worn.

Additional support for the contention that population characteristics contributed to the range of heat tolerance exhibited in these studies come from experiments performed either in the laboratory or a field setting. We recently compiled data from both field and laboratory studies performed by our Institute over the past 35 years (8). Volunteers participating in the field studies came from military units training in hot climates whereas for the laboratory studies, the volunteers were primarily soldiers stationed at Natick, MA and heat acclimated for 3-12 days prior to participation. Analysis of core temperatures at exhaustion between the two settings revealed that only 50% of subjects participating in the field studies incurred exhaustion from heat strain at core temperatures below 39.5°C while 50% of the volunteers in the laboratory studies incurred exhaustion below 38.7°C. What specific factors contributed to the differences between groups is not known, but the effect persisted even when low-heat tolerant individuals (persons stopping at core temperatures below 38.3°C) were removed from the dataset.

McLellan and Selkirk (5) directly evaluated the impact of aerobic fitness and regular physical activity on the ability to tolerate uncompensable exercise-heat stress and reach high core temperatures before exhaustion. Subjects in the study were matched for either fitness or fatness and assigned to one of 4 groups: high fit-low fat, high fit-high fat, low fit-low fat or low fit-high fat. The authors found that the individuals who were fit could perform longer than the low fit groups and reached higher core temperatures before becoming exhausted from the heat stress. Thus, these data document that persons who have a high aerobic capacity are more likely to be heat tolerant than those who are less fit and further support the hypothesis that intra-experiment population differences explain at least part of the reason for the broad range of heat tolerance observed in studies of soldier populations compared to endurance trained athletes.

Conclusions

In this study, heat intolerant volunteers were more likely to develop respiratory distress and muscle cramps while heat tolerant persons were able to continue until cardiovascular and illness symptoms limited further effort. The results suggest that different physiological mechanisms contribute to the inter-subject variability in tolerance to uncompensable exercise-heat stress.

Acknowledgements

The views, opinions and/or findings in this report are those of the authors and should not be construed as official Department of the Army position, policy, or decision unless so designated by other official designation. Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USMRDC Regulation 70-25 on Use of Volunteers in Research. Approved for public release; distribution unlimited.

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